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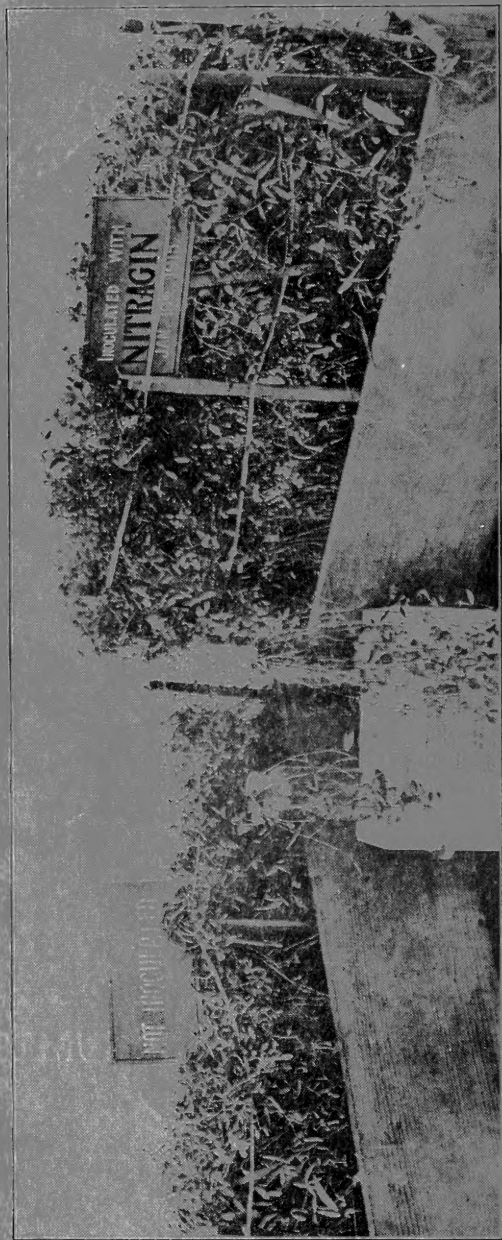
Number 1



NITRATING THE SOIL BY INOCULATED LEGUMES

Bailey

Monograph



Photographed February 24th, 1915

COMMON VETCH (OREGON)

Courtesy Armour Fertilizer Works

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NITRATING THE SOIL BY INOCULATED LEGUMES

BY

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FOREWORD

Agriculture is no longer simply a method of getting a living, but is a real business enterprise managed and controlled with scientific accuracy and all engaged in it are ever hunting for new secrets of success.

This paper has been prepared partially to answer numerous inquiries impossible to answer by mail, but mainly to call attention again to one of the duties everyone who tills the soil owes to the Nation, and in that sense it is **an appeal to patriotism.**

The intention is to be practical rather than technical, for the man engaged in farming wants to know the points of practical value in a positive or negative way. No claim of originality is, nor can be, made in work of this kind, but some of the authorities consulted are referred to by number for the benefit of those who wish to study some points more fully.

All know that the soils of Palestine, which once flowed with milk and honey, are now a barren waste. Everyone realizes that the fertility of soils ought not to be reduced; that high civilization cannot be maintained unless there is an abundance of food products. Many know that **NITROGEN** is the most expensive and difficult plant food there is to get, especially at the present time when nitrate of soda is **contraband of war.** Some know that Nature has a remedy for the deficiency; that **it is possible to obtain unlimited supplies of NITROGEN from the air at small cost,** by means of inoculating legumes with **nitrogen bacteria.**

Success with nitrogen bacteria is a simple and not difficult combination of science and sense and calls for only moderate thoughtfulness and care.

Inoculation of soils has already passed the experimental stage and is established as an agricultural necessity. Farming without the aid of bacteria would be an impossibility for the soil would yield no crops.

The soil is the support of agriculture, and agriculture is the support of the nation. It is evident, therefore, that an intelligent control of the beneficial bacteria is a matter of **National importance.**

The wealth of a State lies in her soil, and her strength lies in its intelligent cultivation. The final destiny of America in fact rests upon the question whether the producing power of the soil shall be reduced, maintained, or increased; and this productiveness must not be temporary but permanent.

The great sciences of physics, chemistry, geology, and bacteriology are the servants of agriculture standing, as it were, with bared arms ready to serve our present and future needs. Agriculture is coming to be a scientific pursuit, and farming is now recognized as a learned profession. The successful farmer of tomorrow will be the one who knows how to handle most skillfully the micro-organisms in the soil.

The imperfect methods of the past led to waste, and the culminating point of success in the future can only be reached under the most capable management. The brain farmer is slowly but surely crowding out the muscle farmer; for work and knowledge are a stronger team than work and work.

The rate of progress is still **too slow** for there is scarcely an area in the world that is producing for man the quantity of food that it should. In the last ten years our population has increased 21 per cent, while the acreage of farm lands increased less than 5 per cent; and the average production per acre is far below that of European countries.

Increased population has led to increased demands without an increased source of supply. The increased value of farm lands makes it necessary to get more out of the soil than ever before, yet the ten year average of wheat in the United States is only 14 bushels per acre. Compare this to the 29 bushels of wheat per acre raised in the older soil of Germany; the 33 bushels raised in Great Britain; and the more than 40 bushels raised in Denmark. (46.)

Americans **waste** plant food. We do not return what we take from the soil. If we keep drawing from our capital,

without making deposits from time to time, our drafts will not be perpetually honored. The merchant sells and buys again keeping up his stock; the farmer sells, and sells, and sells, until he is practically **sold out**. The parable of the talents is as significant now as when it was uttered; and to us are given talents never given before.

The fate of the Nation lies in the progressive farmers who do not bury their talents but keep them alive; the men whose public spirit, patience, and watchful care maintain the fertility of the soil.

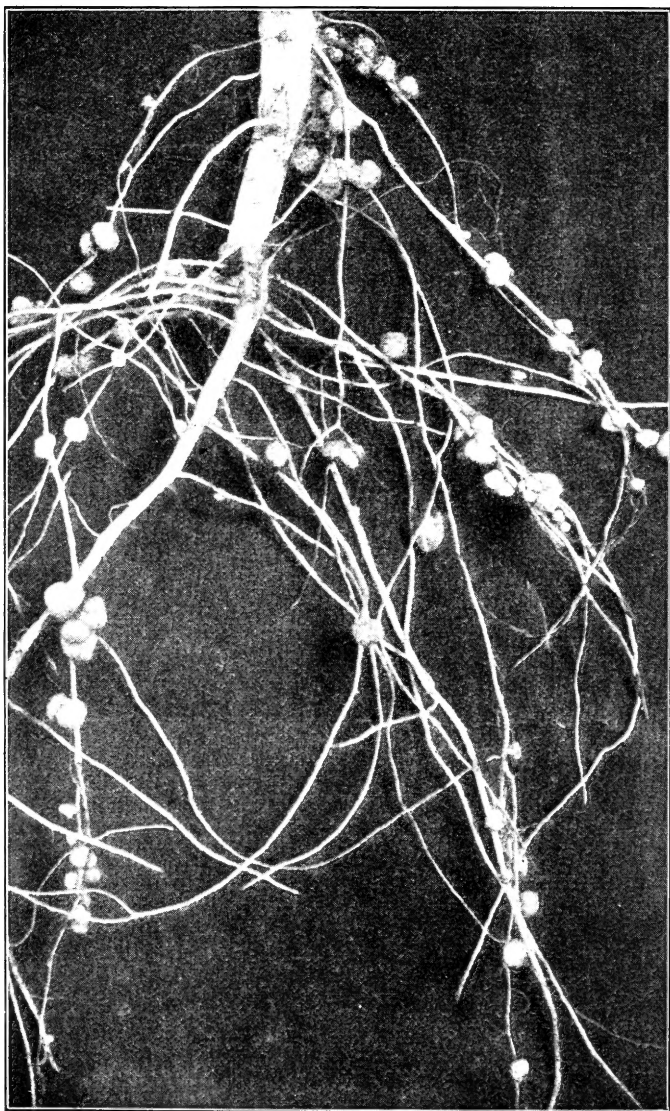
KEEP UP THE FERTILITY OF THE SOIL! Do not leave your children with only a memory or a tradition of the bountiful harvests of former times. The owner should increase the fertility of his land for his children's sake; the tenant should leave the farm better than he found it. If he who "makes two blades of grass grow where one grew before is a benefactor," then he who reduces the fertility of the soil is a public curse. For the sake of humanity, for the sake of our own nation see that the land does not grow poorer but **richer** from year to year.

THE BACTERIA

All organic matter, that is all dead animal and vegetable material, begins to decompose, decay, or rot as soon as it is buried in the soil.

This is Nature's method of sanitation, and of keeping perfect the cycles of life. Everything is at once **taken apart** and each part made ready to **use over again**. (31.)

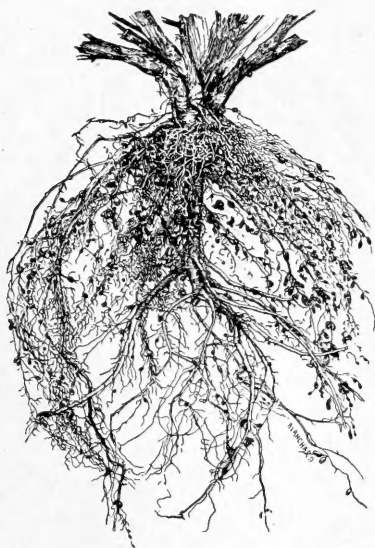
This work is done by various kinds of bacteria, each having its specific task to perform. There are two varieties present in all soils, to a greater or less extent, whose work it is to separate the nitrogen from the complex organic compounds which are useless for plant food. One variety converts the nitrogen into nitrites, and the other converts these into soluble nitrates; a form that can be used by plants as food.



U. S. Dept. Agriculture.

COWPEA TUBERCLES

There is a still more valuable kind of bacteria that possess the peculiar and most valuable power of **TAKING NITROGEN FROM THE AIR AND CONVERTING IT INTO NITRATES**, ready for use by the plant as food. These bacteria live in **nodules** on the roots of legumes, and are generally known as the **nitrogen bacteria**. (1, 5.)



U. S. Dept. Agriculture.

Roots of Red Clover Showing Nodules

They are single-celled organisms somewhat closely allied to the yeast plant; and are as harmless to man, beast, or plant, as the yeast germ itself.

They are classified as plants but are on the border line between the animal and vegetable kingdom where any strict division must be a purely arbitrary one. Analysis shows that they are about 80 per cent. water; the ash con-

sisting largely of **phosphoric acid**, with notable quantities of **potash** and **lime**; while there are only traces of sulphur, iron, magnesium, and silica. (8, 6, 14, 36, 37, 38,)

In method of reproduction they are classed with the **schizomycetes**, or fission fungi, for they multiply by elongating a little and then dividing into two equal halves; each half soon growing to mature size, ready in turn to divide. They are so minute that 25,000 of them would only make a line an inch long, and they must be magnified from 600 to 1200 times before the human eye can see them. The germ comes to maturity in 20 minutes and then divides, so that in 40 minutes there are four young germs that in 20 minutes more will be eight; and in a week billions will be in existence.

This rate of growth is of course not maintained, but is checked by lack of food, by the substances they secrete, by temperature, and many other causes; yet they exist in numbers beyond human comprehension, as a single nodule may contain more thousands of inhabitants than our largest cities.

They grow and do their work in **perfect darkness** and are killed almost instantly when exposed to the full action of the sun's rays. This is due to the actinic and not to the heat rays.

While they are easy to kill in some ways, in others they are **very resistant**, going into a spore or hibernating condition which serves to tide the species over a period of dryness, famine, or unsuitable temperature, and to preserve alive in a hostile environment a sufficient number of individuals until favorable conditions return. (22, 1, 5, 4, 34, 55.)

Hellriegel and Wilfarth in 1886 showed that the tubercles were associated with the assimilation of free nitrogen (30, 7)

and since then the life history of the germs **HISTORICAL** has been worked out by scores of scientists such as Atwater in America; Lawes and Gilbert in England; Boussingault, Ville, Pasteur, Schlossing, and Muntz of France; Nobbe in Germany, and Winogradsky of Russia. Their work has been verified at Agricultural Experiment Stations all over the world, and the farmer can

now utilize this method of obtaining nitrogen, feeling that he is not experimenting, but using established facts and well-known truths. (21, 13, 3, 7, 30, 18.)

Legumes, such as soy beans, cow peas, vetch, alfalfa, etc., form a **plant partnership** with the nitrogen bacteria that is of immeasurable value to agriculture.

PLANT PARTNERS It is not a parasitic relationship where one of the plants is injured while the other is benefited; but it is one of **mutual helpfulness**. The legume furnishes **the home** for the bacteria, and in its sap, or juice, most of the nourishment upon which the bacteria live. The bacteria gain entrance to the roots of



Courtesy Armour Fertilizer Works

RED CLOVER

Seed not
Inoculated

Seed Inoculated
with "Nitragin"

legumes through the hair roots, causing a very definite tissue reaction at the point of invasion. Once having gained entrance they confer upon the plant **immunity from other bacteria**, as only bacteria of higher virulence than those in the nodules are able to enter the roots. (1, 5, 22.)

The nodule, or tubercle, found on the roots of legumes is the **home of the bacteria** somewhat as the ball on the willow twig is the home of the insects within.

THE NODULES The nodule itself is an expansion, or excessive growth of the cells of the legume root, and varies in size from a pinhead to a pea according to the legume it grows upon. During the early stages of growth long thread-like sacs, or tubes, **force their way** through the root cells, and the bacteria live in these sacs.

The nodules are **home fertilizer factories** where the bacteria take the **nitrogen from the air** and convert it into soluble nitrates which **pass at once into the plant circulation**.

It is the **air IN the soil** which the bacteria use, not the air above the soil, and the accumulation of nitrogen takes place first of all **inside the nodule**. It is evident, therefore, that the soil must be **porous** so that the air can **get down** to the root hairs, or the bacteria will have no nitrogen to work on. (30, 7, 9, 14, 22.)

The permanence of the bacterial life is most important and the farmer should note carefully the things that affect their continued existence in his soil. While **LONGEVITY** they multiply rapidly, and die with almost equal rapidity, permitting the **host plant** to profit by the nitrogen they have combined into nitrates; yet they are after all **very persistent** and maintain their continued existence against great odds. There is only a scanty growth of the germs unless **free oxygen** is present, hence **the soil must be deeply aerated**. Since they feed during their growth they are affected by the food the plant feeds on, as well as effecting profound changes in the material upon which they feed. The soil must, therefore, be **adapted to the host plant** or the sap will not stimulate the growth of the germ. The bacteria are live, sensitive plants, requiring **free oxygen** and easily destroyed if contaminated with filth, and are, therefore, **injured** by some forms of **organic matter** such as too fresh manure, and highly concentrated decomposing masses. (30, 27, 10.)

The nodules are windowless little houses and the bacteria live and **work in darkness** while unlocking the soil nitrogen, and are **easily destroyed by light**. **Inoculated seed should be kept in the dark until used**, and protected from sunlight as far as possible while planting.

A **drought** will not kill the nitrogen bacteria but renders them **inactive** for the time, and thus diminishes the percent of nitrogen gained; and a continued drought makes it difficult to **revive** the germs **from a dried condition**. (19, 26.)

Every organism, animal or vegetable, has what is known as its **optimum**, or best, **temperature** at which point it is most vigorous; and each has its maximum and minimum temperature at which its characteristic activities cease. The



Courtesy Armour Fertilizer Works

COW PEAS

Seed not
Inoculated

Seed Inoculated
with "Nitragin"

optimum temperature for the nitrogen bacteria is 36.6° C, or 98° F; although nitrification may proceed in a measure from 4.4° C, or 40° F to 54.4° C, or 130° F. (12.) The lowering of the temperature affects the bacterial activity, yet they **survive winter freezing**, remaining dormant in their little nodule houses; but their activities are of no importance beyond keeping the species alive. (41.) This is an advantage as no soluble nitrates are produced to be **lost by the leaching of the spring rains**.

Bad soil conditions, and a lack of potash and phosphorous for the host plant may starve the bacteria into a degenerative stage of branched and vacuolated forms that do not grow or form colonies. (19, 20, 27.)

Science does not yet know what different **species** there may be among the nitrogen bacteria, but it does know that **there are different types** or varieties each adapted **VARIETIES** to its particular legume. Cow peas demand one variety, soy beans another, alfalfa still another, and so on.



Courtesy Armour Fertilizer Works

ALFALFA

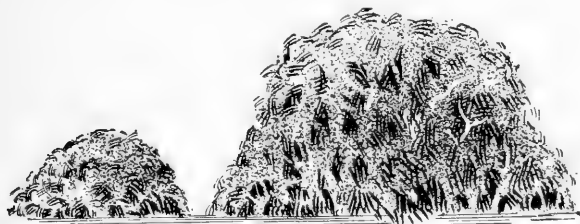
Seed Inoculated
with "Nitragin"

Seed not
Inoculated

Varieties adapted to one legume may be unable to produce nodules on another species, and germs that were **very active** when associated with one species of plant may refuse to

form nodules on the roots of a closely allied species. (54, 22.)

By selecting legumes having vigorous growths of tubercles many of the most useful varieties have been segregated and the **breeding of pure germs** has **PURE BRED BACTERIA** become a business, a science, and as much of an **economic necessity** as the breeding of high-grade cattle. The high-bred germs are **more vigorous**, and therefore more resistant to drought, and other unfavorable conditions.



Courtesy Armour Fertilizer Works

ALFALFA

Seed not
Inoculated

Seed Inoculated
with "Nitragin"

They give the quickest and **shortest road to success** and it is always wisest to depend upon **pure cultures for inoculating** the seed.

Most soils are not naturally supplied with the nitrogen bacteria; and there are other soils in which they are already present but not in sufficient quantities, or of good grade. It is like a man having some mongrel range cattle on his ranch. He must invest in **blooded stock** in order to bring his ranch up to the grade necessary for making the most money. The clover bacteria were not originally found in Illinois soils, causing a failure of red clover under otherwise normal conditions. Alfalfa was pronounced a failure for years in Illinois because there were no alfalfa bacteria naturally in the soil; but the crop is now a success wherever the bacteria have been introduced. The

soy bean bacteria did not exist in Connecticut soils and had to be introduced; and the investigations made in many other states give additional illustration of this fact. (53, 54, 49.)

Only such plants as develop tubercles are able to increase the amount of nitrogen in their tissues. No leguminous plant is able **of itself** to secure nitrogen **NO NODULES**, from the air, but each legume must be **NO NITROGEN** provided with **the particular variety** of bacteria which has the power to live upon its roots and gather nitrogen **from the soil atmosphere**. The marked effect of inoculation is seen on the growth, color, and composition of the plant even though only half a dozen large nodules form on the roots. The greater the number of the nodules the better the growth. Plants without nodules show no increase; those with a moderate number show a slight increase; while those with abundant tubercles grow luxuriously and show the largest increase in nitrogen. (23, 19, 20.)

There is no time when plants are so susceptible to injury by unfavorable soil conditions as in the early period of their growth. Plants sprout readily and for **THE NITROGEN** a short time grow vigorously, then the **HUNGER STAGE** vigorous growth ceases and the plant seems to be suffering for lack of food. This is **the nitrogen hunger stage**, a period in which the plant not inoculated has used up all the nitrogen in its seed; and unless the seed was inoculated the baby roots have to begin searching through the soil in all directions for the nitrogen the plant must have. In the meantime the **top growth has to wait and starve** until the supply has been found and the nitrogen begins to come to the plant. The uninoculated plant **leads a struggling existence** until supplies of soluble nitrogen have been found in the soil. If the seed has been inoculated, as soon as it sprouts and the roots begin to grow the bacteria begin to supply the nitrogen which the baby plant **at once assimilates**, giving a vigorous growth from the start, and absolute protection from the nitrogen hunger. (53, 46.)

THE SOIL

Primitive methods have led to the belief in lack of soil fertility. The record of the human race in the past has been one of ruined lands, in Palestine, in southern **FERTILITY** Europe, in Russia, and in the eastern part of the United States. The slogan of the present is **increase the fertility of the soil**. We must not be satisfied with a temporary system of agriculture in which the available food steadily decreases; but we must demand a permanent system in which **all** the available plant food is perpetually maintained. It will not do to drift with the tide waiting for something to turn up. We must be alert to seize every discovery of science and utilize it. We must know the inner mysteries of the soil as we know the inner mysteries of plant life.

Soil fertility is the **crop producing power of a soil**, under the best conditions; and this fertility depends largely upon three factors: **first** and most important, **the physical character**; **second**, the **bacteriological** character; and last the **chemical composition**.

The soil has two functions; first, it furnishes a home, a mere lodging place for the plant in which it lives and moves and has its being; second, it furnishes food for the nourishment, growth, development, and maturing of the plant. If the physical condition of the soil is poor, or the chemical composition unusual, no amount of inoculation will produce crops equal to those grown on fertile soils. Maintaining the fertility of the soil means that there shall be preserved **within the soil** sufficient amounts of soluble plant food of the various kinds necessary to produce maximum crops. The growing of inoculated legumes is **absolutely essential** for maintaining the nitrogen supply, and necessary as a part of any economic system which shall maintain the fertility of the soil; of any system that will make a poor soil fertile, and keep a good soil fertile. (54, 26, 17, 39, 6.)



U. S. Dept. Agriculture.

Hairy Vetch and Rye Growing Together

The absolute essentials in the growing of crops are: 1, the seed; 2, the soil, or home and lodging place; 3, the food; 4, the drink, or moisture; 5, **ABSOLUTE ESSENTIALS** the heat; 6, the light; 7, freedom from weeds; 8, freedom from disease.

Any one of these factors may limit the yield of crop. Poor seed is poor economy. Proper soil conditions are as essential to the life and activity of the bacteria as they are to the growth of the plant.

The inoculation of the seed is **only one step** towards success, and no matter how carefully carried out, will fail if the other things just as essential are not looked after.

Each type of soil is specially **adapted to specific crops** and this adaptation should be closely studied. There should be reason and moderation in all **CROP ADAPTATION** things. Some want to grow alfalfa and other crops on soils not adapted to them, by applying bacteria, and then complain of lack of success. Such ideas, and such practice are **not** a part of intelligent farming.

The quantity of active nitrogen furnished the plant depends more upon the physical condition of the soil than on its nature and composition. Nitrification is a **AERATION** process of **oxidation** as well as combining nitrogen, and the soil must contain oxygen. As all the nitrogen obtained must come from the air **in the soil**, the soil must be porous so that the atmosphere may penetrate it. The deeper the air penetrates the soil the deeper the nodules will be found and the greater the quantity of nitrogen obtained. Thorough cultivation of the soil and **DEEP PLOWING** are necessary to thoroughly aerate it. This aeration also **reduces in number** certain other kinds of soil bacteria that are **inimical** to the nitrification process. (19, 42, 6.)

The number of bacteria in a soil is closely related to the moisture conditions, and even slight differences in the amount and kind of moisture present may readily cause differences in crop production and in bacterial activity.

The soil must not be too wet, or water-logged; and it must not be too dry. There should be a good supply of water vapor and film, or hygroscopic water, maintained by good capillary conditions. If the voids are filled with water the air cannot penetrate the soil. The root hairs feed in the films of moisture clinging to the soil particles, and this supply is kept replenished by capillary action drawing up water from below. (19, 20, 11.)

The number of bacteria in soils decreases as the temperature is lowered, being practically at a minimum when the soil is frozen. When the soil temperature does not go far below the freezing point the mineral matter in the film water may keep it from freezing and bacteria may multiply to some extent, keeping the species alive without hibernation. Thorough cultivation of the soil admits air, warming the soil as well as draining off excess water. The great difficulty in cultivation is that plows and other implements do not go deep enough. This has led to the introduction of **plowless agriculture**, or loosening up the soil by means of explosives. As nearly all legumes will send their roots very deep if permitted by the soil conditions the use of explosives is of special benefit when inoculating with nitrogen bacteria. (7, 12, 6.)

The use of explosives sets free plant food; plows deep without mixing the subsoil with the top soil; admits oxygen of the atmosphere to the organic matter in the soil hastening decomposition; admits nitrogen of the atmosphere to the roots, promoting bacterial nitrification; makes all the soil available by fining it; breaks up hard pan; makes a reservoir for water; warms and dries the soil; saves the rain by taking it into the soil; prevents evap-

oration and conserves moisture; permits the roots to go deep down into the soil; makes the moisture of the subsoil available; makes the plant food in the subsoil available; and converts subsoil into fertile soil, deepening the feeding zone of the roots. (74.)

PLANT FOODS

Crops are not made out of nothing but are built up from food elements just as a building is made of wood, iron, brick, stone and mortar; for without materials nothing material can be made.

A few simple facts should be kept in mind, viz: that 95 per cent of most plants consist of carbon, hydrogen, and oxygen; and that the remainder consists mainly of nitrogen, potassium, and phosphorous; with minute quantities of iron, lime, magnesium, silica, etc.

There is no market value to the carbon which the plant inhales through its leaves; or to the hydrogen and oxygen which they obtain from water; or

NO MARKET VALUE to the calcium, magnesium, iron and sulphur because only minute amounts are required and because they are practically present in ALL SOILS in sufficient quantities for plant growth.

There is a high market value to nitrogen, potash, and phosphorous because all plants require considerable quantities, and they are naturally present in soils in rather limited quantities.

Plants require balanced rations as much as cattle, and adding nitrogen to a plant starving for potash or phosphorous will do no good and only tends to still further unbalance the food supply.

Potash is obtained largely from the mineral deposits of potassium salts, from wood ashes, and should also be obtained from the inexhaustible supplies of sea kelp. Phosphorous is obtained from rock phosphates, slag phosphates, bone meal, etc.

Small quantities of nitrogen oxides are formed by electrical discharges through the air and are washed down by the rains. Organic nitrogen exists united with carbon, hydrogen, oxygen and other elements in the form of partially decayed vegetable and animal matter, but is insoluble in that form and unavailable for plant food. It is contained in ammonium salts, in dried blood, and cottonseed meal, and other sources.

The principal source, however, has been sodium nitrate, also known as niter, and Chili saltpeter, the main supply coming from the deserts of Taramaqual in Chili.

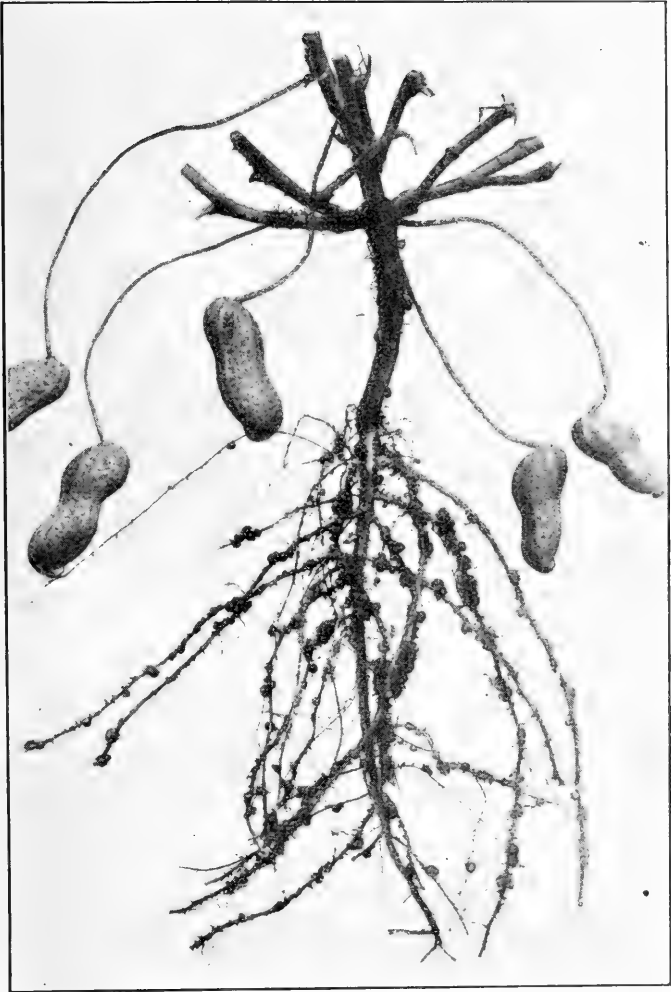
Sodium nitrate contains 15 to 16 per cent of nitrogen; ammonium sulfate 20 to 21, and dried blood 12 to 15 per cent.

The manufacture of calcium nitrate by uniting atmospheric nitrogen with lime by means of powerful electrical discharges was started abroad a few years ago, but this supply is now shut off by the war.

The cost is excessive and no farmer can afford to purchase a pound for general farming. Only market gardeners who take off several crops of high market value a year, or those raising special crops like oranges and lemons can afford to use the commercial forms of nitrogen fertilizers.

Mineral nitrates are easily lost because they are very soluble, and if left in the soil in the fall or formed during the winter may be largely lost before spring by percolating waters unless the land is covered by a crop that will take them up.

It is often difficult and expensive to apply them at just the proper time, when the plant, tree, or crop needs them most.



U. S. Dept. Agriculture.

Roots of Peanut Vine, Showing the Value of this Plant as a Nitrogen Gatherer. The Nodules on the Roots are formed by the Bacteria which collect the Nitrogen.

Very large quantities of nitrate of soda are necessary to bring crops, from barley to oranges, upon a par with those supplied by legumes.

The crop uses **only the nitrogen** and does not need the soda, and the **continued use** of nitrate of soda may have an **injurious effect on the soil**, even to producing an alkali condition.

With mineral nitrates one does not get the benefit of **added humus** and organic matter as when the legumes are plowed under and decompose in the soil. (49, 42, 45.)

Nitrogen is removed from the soil not only by crops grown, and by drainage waters, but also by the blowing off of the surface soil; and by the action of denitrifying germs, and the losses this way may be several times the amount used by the crops.

If any question pertaining to the science and practice of agriculture is settled it is this—that **the atmosphere is the most economical source of nitrogen**

NITROGEN FROM for all general farming.

THE AIR

The atmosphere consists of a mixture—not a combination—of 79 volumes of nitrogen to 21 of oxygen; or by weight, 77 per cent of nitrogen to 23 of oxygen. In the air nitrogen is inert, combining with nothing, and only serving to dilute the oxygen. The atmosphere gives **an inexhaustible supply**, for all that is drawn from it returns again in the cycles of plant and animal life. It has been estimated that if the population of the earth was 1000 million it would take 3800 years for their respiration to use up one per cent of the oxygen of the air, if none was returned in the meantime; and there is about four times as much nitrogen to draw from as there is oxygen. There are about 75 million pounds of nitrogen resting on every acre of soil, pressing down upon it nearly 15 pounds per square inch, or more than a ton to the square foot. The air over each acre of land contains sufficient nitrogen for a hundred bushel crop of corn every year for 40,000 years; and owing to the cycle of life from soil to plant, from plant to animal, and from animal back to the soil, the supply is per-

manent. This free and inexhaustible supply cannot be used by any plants except legumes, and they cannot use it unless the nitrogen gathering bacteria are present. (54, 50, 23, 25, 34, 42, 55.)



U. S. Dept. Agriculture.

Roots of Soy Beans, Showing Nodules

Varro wrote before the Christian era that lupines were plowed into a poor soil in lieu of manure; but agriculture has had to wait for centuries to know why

THE LEGUMES and how the lupines fertilized the soil.

All plants which bear their seed in a capsule or pod, such as clover, alfalfa, peas, beans, vetch, peanuts, etc., are known as legumes.

The legume itself has no power to fix nitrogen. This power rests wholly with the bacteria in the nodules on the

roots of the legume, which do have the power to take the **free nitrogen from the air** and unite it with other elements forming nitrates which are dissolved in the juices of the legume.

The farmer secures the presence of these bacteria by **inoculating the seeds of the legume before planting them**. A legume that has no bacteria nodules is a **soil robber**, for inoculated legumes grow just the same as other plants and must get their nitrogen from the soil the same as non-leguminous plants.

Each legume must have **its own particular variety of bacteria**. In fact one of the most dominant **causes of failure** or unsatisfactory growth of some of the most valuable legumes is the absence of the proper nitrogen gathering bacteria.

Today the farmer can get all the germs he wants and **sow them** with the legume seed, thus taking a most important step towards insuring a perfect stand and **stocking the soil with nitrogen**.

It is easy to see if the bacteria are present, for all that one has to do is to pull up a few plants and see if the nodules are there on the roots. Where the plants are sparsely infected the individual nodules develop to an enormous size, but few in number. Where the soil is well infected the individual nodules are much smaller and more numerous.

Legumes are deep rooted plants and require thorough and deep tillage of the soil. This increases their value to the farmer for it carries nitrification deep down, fertilizing the soil to depths that no other method can.

As the legumes approach maturity the nitrogen is largely absorbed from the tubercles and stored in the tops and roots of the host plant; then if the legumes are plowed under **all this nitrogen**, together with millions of the germs are distributed in the soil. They should be plowed under before the crop fully matures so that thorough decomposition may quickly occur. (53, 54, 49, 2, 4, 28, 33, 57, 59.)

Nitrogen bacteria cannot live in an acid medium and are absent from acid soils. The decay of leaves and the decomposition of organic matter usually produces acids that kill off the little workers and put an end to their usefulness. Even soils which overlie limestone may be acid in their first foot or two. The soil should be tested with litmus, or other reagents, to be sure that it is not acid. (1, 5.)

There is a class of bacteria that are denitrifiers setting soil nitrogen free again. They do not live in nodules, but are abundant in manure heaps and in all decomposing heaps, and diminish rapidly when the manure is well rotted. Only well-rotted manure should be used where legumes are planted, and then only in limited quantities. Denitrifying germs are particularly active in soils carrying a limited amount of air, and in water-logged soils. These facts again emphasize the necessity for thoroughly and deeply cultivating the soil. (1, 5.)

If no alkaline element like lime, potash, or magnesium is present in the soil no nitrate can be formed. The lime supplies the base for uniting with the nitrogen and oxygen in forming the soluble nitrates. Its presence is necessary also to neutralize any acid in the soil. Old air slacked lime, fine ground limestone, and marl are the most economical forms to use. Fresh burned lime, or fresh slacked lime are not advisable as they tend to attack and destroy the organic matter in the soil, or "burn the land." Fifty-six pounds of lime will furnish 74 pounds of perfectly dry slaked lime. The amounts required vary widely according to local conditions. In some soils 1000 pounds of limestone per acre is ample, in others three tons per acre are required.

Lime helps to conserve the moisture and aid in carrying the bacteria through a period of drought. It is also of indi-

rect benefit in unlocking potash and phosphorous that are present in the soil but unavailable. (54, 19, 49, 29, 32, 56, 75.)

All soils are not adapted to the same legumes. One soil may be specially adapted to beans, producing a large crop, developing quantities of nodules and fixing an abundance of nitrogen, yet the same soil may not support alfalfa or other species of legumes nearly as well.

VARIETIES OF LEGUMES

Fortunately there are a large number of legumes that have been bred to a high state of perfection, together with their specific bacteria, giving an assortment covering nearly every peculiarity of soil and climate.

Alfalfa, the queen of forage plants, is a muscle-building feed, while corn is a fattening and heating feed, and together they make an excellent ration for any animal on the farm. Alfalfa roots go down to great depths, 12 to 20 feet being common; while 65 feet has been noted in California. This deep rooting habit enables it to stand drought, and is of special value because large quantities of mineral plant food are brought up from the depths. (40, 44, 47.)

There is a world-wide demand for **Peas** and **Beans** as food for the human race, and they can also be readily converted into milk, pork, mutton, beef, and other **cash money** products. (58, 60.)

The **Cowpea** and the **Soy Bean** will grow upon land too poor to grow anything else. They are used in the rotation of crops to maintain fertility; and as a supplementary feed to balance other rations in feeding animals. They may be sown with grain and corn or used after oats as a fertilizer or catch crop, or as an orchard cover crop cultivated during the season and then pastured off with hogs. Inoculated cowpeas contained 4.09 to 4.33 per cent of nitrogen in their tops and 1.42 to 1.53 per cent in the roots, while those not infected contained only 2.32 to 2.69 per cent in the tops and .88 in the roots. (54, 35, 48, 51, 61, 62, 64, 72.)

It is often difficult to get at catch of **Clover** on new land because its bacteria are not present in the soil, but a good catch or stand is secured if the clover seed is inoculated.

Clovers make potash and phosphoric acid in the soil available; protect the soils from blowing and washing; change loose sand into a compact loam with greater moisture holding capacity; and make stiff clays more open and friable, allowing better aeration. They make good cover crops for fields in the winter, from corn to cotton. (15, 16, 63, 66, 71, 73.)



U. S. Dept. Agriculture.

Peanuts Growing in the Alleys Between Rows of Corn

The common, or summer **vetch** is extensively used on the Pacific coast and in the southern states as a winter hay crop being **sown with** oats, rye, or wheat; and in the citrus groves as a winter green manure crop.

The winter, or hairy **vetch** is more resistant to cold than any other annual legume grown. It is used as a green manure and cover crop on tobacco lands and in orchards. (69, 70.) The **lupines** make a rank growth and are exten-

ively used in Germany for putting humus and nitrogen into sandy soils.

The **sanfoin**, or **esparsette** is similar to the clovers in some respects. It may be sown with any of the grains as a nurse crop, and later cut for hay or turned under for humus and nitrogen. One of the most valuable annuals is the **serradella** as it remains green under the snow in winter, giving winter pasture. It is also valuable for recovering sandy wastes, for cover and nurse crop, for feeding stock, and as a green manure being plowed under in the spring to be followed by potatoes, corn, or cereals.

Nitrogen germs will not develop on the roots of non-leguminous crops and it is useless to inoculate their seed. They must be furnished with nitrogen by the legumes. Cowpeas, crimson clover, vetch, etc., are inoculated and planted between the rows of **corn** or **cotton**, and plowed under after the harvest. The clovers, sainfoin, serradella, etc., are often sown with **wheat**, **oats**, **rye** and other cereals, and the whole crop is sometimes turned under as a green manure. Alfalfa, clover, vetches are inoculated and planted between the rows of **orchards** and **small fruits** and plowed under for the humus and nitrogen. Some legumes, like the black-eyed bean, peanuts, etc., are made a source of income while the young orchard is growing. Legumes do not make a sod difficult to work and may be planted ahead of crops such as hops, cotton, tobacco, asparagus, potatoes, and grain, or in fact of any crop that needs nitrogen.

The benefits derived from inoculating legume seed with the nitrogen bacteria are threefold: 1, it increases the crop; 2, it increases the food value of the crop; 3, it increases the fertility of the soil. Evidence on these points is readily obtained from any of the many agricultural stations. It is well known that inoculated crops sprout quicker, grow faster, have a darker, richer green color, and larger blossoms. Bacterial nitrogen is **better distributed through the soil** than mineral or organic nitrogen,

and two tons of clover or cowpeas plowed under may have greater power to liberate plant food than 20 tons of old, inactive matter in the soil. Bacteria can put from 150 to 200 pounds of available nitrogen in each acre, where the legumes are properly used; and this is worth from \$25 to \$30 per acre according to the market value of nitrates. In New Jersey the **increase in dry matter** by inoculation was, for alfalfa 500 per cent; beans 75 per cent; while cowpeas more than doubled. (24.25.) The University of Illinois says: By proper inoculation we have grown a crop of alfalfa which contained as high as **17 times** the quantity of **nitrogen** as was contained in a crop grown without inoculation but otherwise under exactly the same conditions. (52.) The same authority says \$1 of lime made more than a \$10 increase per acre in alfalfa hay, and \$4 of phosphorus made an additional increase of hay, while the **presence or absence of alfalfa bacteria made the crop a success or failure respectively**. (50.) Canada field peas inoculated by **pure culture** supplied more than seven times the amount of nitrogen furnished by those not inoculated.

The increase in corn in Iowa was from 52 to 68 bushels, and in oats from 33 to 55 bushels. (19) In Alabama the inoculation increased the yield of hairy vetch 89 per cent, of Canada field peas 138 per cent, and of crimson clover 146 per cent. (2.) In Arkansas, legumes were grown and turned under on cotton land and corn land with the following results: Cowpeas gave 1335 pounds of seed cotton per acre; soy beans gave 1448 pounds; and velvet beans gave 1550 pounds of seed cotton; the corn lands gave with the cowpea 37 bushels per acre; and with the soy beans 42 bushels of corn per acre. (4.)

Protein is the general name for a series of organic compounds that contain nitrogen in addition to oxygen, carbon and hydrogen. One group consists of the **INCREASE IN PROTEIN** final nitrogenous organic compounds called **PROTEIDS, which constitute the FLESH,** (not the fat) and **VITAL ORGANS** of animals, and the protein of mature plants. The number of proteids is very large, and all contain nitrogen, usually about

16 per cent, and some of them also contain phosphorous and sulfur. The high cost of living is already calling attention to the special value of peas and beans, as **they contain as much protein as meat**, and the best way to insure this supply is by inoculating the seed. The more protein there is in the crop, the **more beef** it makes when fed to stock.

Soils are never so rich but that their quality may be improved, or so poor but that they may be made to produce good crops. Where there is a de-

BENEFIT TO THE SOIL ficiency of humus or decomposing organic matter in the soil a green manure crop of inoculated legumes should be plowed under, **increasing the fertility** of the soil; **increasing the yield and food value** of succeeding crops; **restoring fertility** to land that now produces little or nothing; and by **stocking the soil with nitrogen** increasing the **CASH VALUE OF THE FARM**.

The masses of the fine roots of the legumes penetrate and hold the soil together during the heavy winter rains and **prevent surface washing**, saving the fertile top soil. They also **regulate the moisture supply**, and modify the ill effects of extreme temperature. They **keep the soil in good physical condition**, the turned under legumes binding together loose sandy soils, loosening up stiff clay soils, and making loams loose and friable.

They are a safeguard against injury to fruit at harvest time. They insure against the wearing out of the soil.

Plants not only secrete food but excrete waste material, poisoning the soil with these toxins, and finally checking their own growth. Some crops are not in-

CROP ROTATION jured by the toxins left by preceding crops in the soil; other crops are injured; and a few thrive. The secret of successful crop rotation lies in selecting a crop that will remove or neutralize the toxins left by the preceding crop. The object of rotation is to preserve the fertility of the soil; to maintain its good physical condition; and to put back **ALL** the plant food removed from it.

It helps to maintain the organic matter in the soil, and is aided by the use of all farm manures, and a liberal use of green manures. Rotation, however, is not enough, as for example in Ohio a five years' rotation of corn, wheat, clover and timothy **did not** secure sufficient nitrogen for maximum crops. The rotation **must** contain legumes. It is not assumed that the bacteria can replace other plant foods, or do away with the proper cultivation of the soil; but inoculation with the nitrogen bacteria is **the secret of success** in successful crop rotation.



Courtesy Armour Fertilizer Works

SOY BEANS

Seed inoculation is not a new discovery, and there is nothing mysterious about it. It is admitted by all authorities that

NO MYSTERY it **can be** successfully performed by any careful farmer who will take the necessary time and pains. **IT IS NOT A CURE-ALL**, and no sensible man will claim it as such; it does not take the place of potash or phosphorous; sweeten sour or acid soils; or remove the necessity of thorough cultivation; but it can **double the yield** of crops where all the other conditions given are favorable.

The best method is to inoculate the seed by treating it with a proper culture of the **special germ** adapted to the legume before planting. The most sci-

INOCULATE THE SEED entific method is to obtain a **pure culture**, for specialists

have succeeded in breeding strong, healthy, vigorous germs which can be sent by mail to the farms and orchards; and are as clearly an economic necessity as pure-bred cattle or pure-bred sugar beets. The cultures should be fresh, as they then contain a larger number of active organisms and are better for inoculating than old cultures.

Use only the best seed, and get them free from weeds. Poor seed is worse than none at all; and bacteria are not weed killers.

Follow the directions of the parties you buy the germs from, only seeing that the seed is **thoroughly wet**; and then spread it out to dry where it will not **mould** or sprout, or **lose its vitality** by exposure to sunlight; or be subject to any of the conditions mentioned that **weaken** or destroy the bacteria. Remember especially that the bacteria are minute, delicate plants that live and work **in the dark**, and should no more be exposed to direct sunshine than a photograph plate. They should be mixed with the seed **when the sun is not shining**, or in the evening; and should be planted mornings and evenings, unless the sky is clouded. Be sure of your dealer, as it has been found in a few instances that some cultures did not contain the nodule-forming germ at all, a mistake easily made by anyone not a specialist, as there are soil bacteria that produce colonies **VERY SIMILAR** in appearance to the tubercle-forming ones. (15, 26, 23.)

Tubercle-forming bacteria will disappear from **some soils** in a few years if the legume upon which they grow is not grown occasionally; while in other soils **PERMANENCE** they seem to remain, becoming **normally present**. Bacteria growing in soil richly stocked with **organic nitrogen** lose much of their power to fix new nitrogen, and the nodules seem to dwindle away

and lose their peculiar function, seeming to follow the general law that unused organs suffer atrophy.

Inoculation is a benefit **wherever nitrogen is needed in the soil**; where the soil has not previously borne legume crops;

**INOCULATION
AN ADVANTAGE**

wherever the legumes previously grown showed only a few nodules, or a weak growth of crop; where the legumes to be grown belong to a species **not closely related** to the one previously grown on the same soil. If you have **bad spots** in a field, take good, sweet, inoculated soil from **the same field**, and **never** from some other field, and spread it on the bad spots.

Every teacher knows that it is easier to teach 20 men what is good to do than to persuade **one man** to do it. Be the one

**CONTROLLING
LOCAL CONDITIONS**

man in your district to **do the right thing**, and that is to find out for yourself if there is any deficiency of any element in **your soil**; and to prove the benefit of **all new material** by means of **test plats**. **TEST PLATS ARE A NECESSITY ON EVERY FARM**; and are far better than any analysis, chemical or physical. They give the prudent method and the cheapest method of checking results. The one-twentieth of an acre is a handy size. Plant one plot with the legume without using any germs or fertilizer of any kind; on another plant the legume and use inoculated seed, without using potash and phosphorus; on another use inoculated seed and potash and phosphorous. Each plot should be treated with lime to neutralize any acidity in the soil. Be careful that water from the inoculated ground does not drain onto plats not inoculated and thus make comparison impossible. When full grown cut an equal area from each plat **and weigh** each separately and compare; but do not trust the eye alone, as a 25 per cent increase may not show unless you weigh. Dig samples of roots from each plot, going **deep** enough to get the entire roots; wash carefully until the roots are white;

put the bunches of roots into separate glasses and let the roots float apart, noting the **form, size and number** of the nodules. Each nodule means so much nitrogen for the land. Do the work carefully, as the nodules strip off easily and may be lost, especially where small but numerous.

Normally, seasonal and climatic conditions vary, and changes in local temperatures and in moisture are constant and one must make allowance for them in his methods of cultivation. Use test plots for checking seed, crops, fertilizers, and different methods of cultivation on your own soil. Investigations of local peculiarities are **not experiments but investments**, a guide towards success, and a protection against loss. Trifles noted may give success, and **SUCCESS IS NO TRIFLE**. Test and know with your own knowledge before condemning anything new in agriculture.

The dangers of inoculation by soil transfers are not imaginary but clearly established at many of the state experiment stations, and it is now considered

SOIL TRANSFERS

folly to try such a haphazard method. It may, and has, transferred plant diseases, noxious weeds, and insect pests. The cost of transferring 400 to 500 pounds per acre from one locality to another is large, and the task is laborious. Many bacteria are killed by the sunshine during the transfer, and the germs are often weak and lack strength to penetrate the roots of the legumes. The inoculation with pure cultures leads to better results. (30.)

Success is a matter of **brain, not brawn**. Have **faith** in the investigations at experiment stations and do not condemn the

PRECAUTIONS

principle, but study the methods that lead to success. The dealer can only **guarantee the purity and vigor** of his bacteria, he cannot **force the farmer** to guard himself against failure caused by not closely observing the **other factors of success**. Most failures come from **neglect to follow directions**. Do not open the cultures until ready to use. Use them only for the crop and acreage as directed. Sow the treated seed as

soon as possible. Do not try to keep some over for future use, as they dry out, and a too long dried condition reduces vigor. Use fresh vigorous cultures, and keep the germs in a cool, clean, **dark place** such as a cellar. Do not let treated seed come in contact with commercial fertilizers. Do not spread seed in the sun to dry. Do not plant the seed when the sun is very bright, or hot. Plant on a rainy or cloudy day, or in the morning or evening. Do not use on an acid soil, but neutralize first with lime. See that the soil contains enough potash and phosphorous. See that the soil is well aerated, well drained, and warm. See that the crop is adapted to your soil, and your local climatic conditions. See that foul grass and weeds are kept out. Do not leave things to your hired help. Success lies in yourself, for to him that hath gumption big crops shall be given.

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Photographed Feb. 24th, 1915

Courtesy Armour Fertilizer Works

Corn Stimulated with Inoculated Beans

Corn not Stimulated

Common Vetch 16 days old

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